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Genotype x Environment Interaction Analysis of Tef Grown in Southern Ethiopia Using Additive Main Effects and Multiplicative Interaction Model

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Abstract

Twenty-two tef [*Eragrostis tef* (Zucc.) Trotter] genotypes were evaluated for their grain yield performances at four locations namely Areka, Humbo, Hossana and Alaba in 2002/03. The objectives were to estimate genotype x environment interaction, to identify stable tef genotypes, and to assess the interaction patterns of the testing locations. Significant ($p<0.05$) differences for grain yield among genotypes were observed at each location; across locations, the effects of location, genotype and G x E were significant ($p<0.05$). AMMI partitioned genotype x environment variance into four Interaction Principal Component Axes (IPCAs), but significant was ($p<0.05$) only the first IPCA that captured 49% of the total G x E variance. The study revealed that the released variety DZ-Cr-255 was highly stable and better yielding variety across the locations. Areka and Hossana showed close IPCA1 scores of similar sign, and coupled with their higher location mean yields, may represent relatively better testing environments.

Keywords: genotype x environment interaction, AMMI model, stability, variety

1. Introduction

Tef [*Eragrostis tef* (Zucc.) Trotter] is the most important cereal grown in Ethiopia. In terms of acreage it occupied about 2.12 million hectares (Central Statistical Authority, 2000) in the production year 1999/200. Tef production has been increasing from year to year and so did the demand for tef as staple food grain in both urban and rural areas. The national average yield, however, is as low as, 8.09 quintals per hectare. Although the genus *Eragrostis* has a wide distribution in Africa, tef is the only cultivated species as a food crop only in Ethiopia and Eritrea (Seifu, 1986). According to Vavilov (1951), Ethiopia is both the center of origin and diversity for tef.

Tef is mainly used for making *injera* (a pancake like bread). It is also used to make porridge and native alcoholic drinks called *tella* and *katikala* (Asrat and Frew, 2001). The straw is high in demand for feed and when mixed with mud it provides the best plastering medium for walls of houses. Nutritionally, tef is no lesser competent than the other cereals grown in the country.

Most cereals are grown in areas with unpredictable environments and the staple Ethiopian cereal, tef [*Eragrostis tef* (Zucc.) Trotter], is no exception. In these environments, crop yields are dependent upon the interaction of the genetic potential of cultivars and the growing conditions. Crop breeders have long realized the importance of genotype-environment interaction (G x E) as it affects the progress from selection and thereby making variety development and recommendation more difficult (Allard and Bradshaw, 1964). Analysis of G x E helps to determine an optimum breeding strategy; breeding for wide or specific adaptations. Moreover, analysis of the G x E variance allows the grouping of similar sites in relation to genotype performance within which the interaction is minimum (Gauch and Zobel, 1997; Annicciarico, 2002). Several biometrical methods have been developed to analyse G x E, and evaluate genotype stability over a range of environments (for review see, Ramagosa and Fox, 1993). The Additive Main Effects and Multiplicative Interaction (AMMI) analysis, which combines analysis of variance and principal component analysis, is the most widely used in recent times for G x E analysis on different crops (Crossa *et al.*, 1991; Yau, 1995; Annicciarrico, 2002).

There are few G x E interaction studies in tef (Tiruneh, 1999; Fufa *et al*., 2000); these were carried out mainly for the environments prevailing in the central highlands of Ethiopia. But tef in this country is grown on over two million hactares under high variation in climatic and edaphic factors that lead to G x E even within a small geographic area (Hailu and Getachew, 2006). In his review on G x E in tef, Tiruneh (2001) has recommended the need for further G x E interaction studies in the various tef-growing regions of the country for a better understanding of its magnitude and nature.

In Southern Nations, Nationalities and Peoples Regional State (SNNPR), tef is the second (proceeded only by maize) most important cereal cultivated by the majority of farmers. Report by Central Statistical Authority (2000) indicates that the total production area is 165,000 ha with an average regional yield of only 0.635 t ha^{-1} (78% of the national average). Currently, multi-location performance tests on tef are undergoing in the Region, but with no quantitative estimation of G x E, which is a prerequisite to formulate sound tef breeding strategy. The objectives of this study, using the AMMI model, were to estimate the magnitude of G x E, to identify stable tef genotypes suitable to grow across the diverse tef production areas of SNPPR, and to assess the interaction patterns of the testing locations.

2. Materials and Methods

Twenty-two tef genotypes (12 released varieties and 10 genotypes in advanced stage of yield trials) were used in this study (Table 2). The plant materials, which were obtained from Debre Zeit Agricultural Research Center, courtesy of Dr. Hailu Tefera, differ in grain color and other agronomic characteristics (Hailu et al.*, 1995). A local check was included in the test genotypes; however, its performance at all the locations was very poor, and therefore, was excluded from the analysis for reasons of fulfilling statistical assumptions.*

The test varieties and genotypes were planted at four locations (Alaba, 1700 m asl, Andosol; Alaba, 1830 m asl, Alfisol; Hossana, 2400 m asl, Nitosol; Humbo, 1400 m asl, Nitosol) that represent the major tef growing areas of SNNPR in a randomized complete block design with three replications in the *Meher* season of 2002/03. Each experimental plot was 2 m long and consisted of six rows spaced 20 cm apart. Distances between plots and blocks were 1 m and 1.5 m, respectively. Sowing at all locations was made starting from end of July to the first week of August based on availability of rainfall and soil moisture. Seed rate of 25 kg ha^{-1} was used. The seeds of tef were mixed with sand (1:4) for uniform distribution in a plot. Fertilizers (DAP and Urea) were applied with the rate of 60 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} N for Nitisol (Hossana) and 40 kg ha^{-1} N and 60 kg/ha P_2O_5 at all the other locations. DAP and half of the Urea were incorporated into the soil before planting and the remaining Urea was applied at early tillering stage. Weeds were controlled manually. Data on grain yield were recorded on plot basis of the four central rows.

Analysis of variance (ANOVA) for grain yield was carried out at each location. Combined ANOVA over locations was carried out after testing the homogeneity of error variances (Gomez and Gomez, 1984). The Additive Main Effects and Multiplicative Interaction (AMMI) analysis was carried out according Gauch and Zobel (1997) using Agrobase^{TM} software (Agronomics Software Inc., 1988). AMMI analysis partitions the G x E sum of squares into interaction principal component axis (IPCAs) and generates scores for the first IPCA, which are helpful to estimate stability (Gauch and Zobel, 1997). Bi-plot, which provides a graphical view of G x E was constructed (Kempton, 1984). Interpretation in a bi-plot representation is that genotypes or environments that occur almost on perpendicular line have similar interaction patterns. Genotypes and environments with large IPCA1 scores, positive or negative, have high interactions whereas genotypes or environments with IPCA1 score of zero (or nearly zero) have small interactions (Zobel *et al*. 1988; Crossa, 1990).

3. Results and Discussions

The combined analysis of variance for the 22 tef varieties and genotypes grown at four locations is given in Table 1. Genotype, location and G x E variances were significant ($p<0.01$), indicating that genotypes performed differently at the different locations. Location accounted the largest (53%) percentage sums of squares (% SS) remaining among location, genotype and G x E. G x E accounted relatively small (27%) but larger percentage of the remaining SS than genotype (20%), thus allowing further variance analysis using the AMMI model.

From the AMMI analysis for grain yield (Table 1), four possible interaction principal component axes (IPCAs) were developed. However, the full model AMMI was retained in the first three IPCAs to capture the whole pattern, which was contained in the G x E. Among these IPCA axes, the was significant ($P < 0.05$). The first IPCA axis (IPCA1) captured 48.70% of the total interaction variance while the second IPCA axis (IPCA2) captured 36.89%. The total portion of G x E variance captured by the two IPCA axes was 85.59%, which is congruent with the results (84%) of Tiruneh (1999). In barley, 37-53% of the interaction variance was explained by the first IPCA alone (Yau, 1995), and in maize, as much as 90% has been reported (Crossa, 1990).

Significant differences ($p<0.05$) among the test genotypes were observed for grain yield at all the individual locations (Table 2); grain yield ranged between 1403 kg ha^{-1} at Alaba and 2493 kg ha^{-1} at Hossana. The differential responses of genotypes were also manifested in their ranking orders. Across locations, the released varieties DZ-Cr-37 (2418 kg ha^{-1}) and DZ-Cr-255 (2309 kg ha^{-1}), and the genotype, DZ-01-1278 (2262 kg ha^{-1}), were the highest yielders.

Tef genotypes under this study showed IPCA scores of different signs and magnitudes (Table 2). Bi-plot graphical representation for genotypes and locations is shown in Fig. 1. Few genotypes had IPCA score values of nearly zero, which implies that they are relatively stable (minimum interaction) genotypes across diverse environmental conditions. Accordingly, the tef variety DZ-Cr-255 was highly stable across the test environments. This variety gave the second highest mean grain yield (2309 kg ha^{-1}), indicating the possibility of simultaneous selection for stable and high-yielding genotypes. The bi-plot also showed that genotypes DZ-Cr-37, DZ-01-1573B, DZ-01-1378B and DZ-01-2507 were relatively stable compared to the rest of the tef genotypes. IPCA1-score list for genotypes also showed that the scores for these genotypes were small (near to zero) showing the inclination of the genotypes to be stable across the test environments. High IPCA-scores for grain yield were obtained for HO-Cr-136, DZ-01-2462 and DZ-01-2457, indicating that these genotypes were highly unstable; bi-plot indicated that these genotypes were better performing only at Hossana, where the highest location mean yield was observed.

A bi-plot of AMMI analysis or IPCA-scores for locations express the effect of an environment on different characters; environments with higher IPCA scores regardless of the sign discriminate among genotypes more than those with lesser IPCA scores (Kempton 1984). Thus, discrimination among genotypes was high at Humbo while little discrimination among genotypes was observed at Alaba. IPCA1 list for environments showed that Hossana also had high genotype discrimination next to Humbo. The IPCA score for Areka and

Hossana were similar in their sign, and their magnitude is close to each other relative to the remaining test locations. Therefore, the two environments could belong to the same interaction group. Positive (but low magnitude) of IPCA-score for Alaba also indicated that there might be few similar agro-climate features of this test location with Hossana and Areka. Tiruneh (1999) has noted that environments with similar altitudinal range, rainfall distribution and soil types, exhibit the same sign for IPCA-score and they were put into same interaction group.

The AMMI analysis was demonstrated to have advantage in partitioning G x E variance over joint regression analysis (Eberhart and Russel, 1966) under the conditions of small or large data settings (Yau, 1995). Because the two IPCAs in the present study have cuptured the interaction variances quite substantially, there are interesting features of practical significance that can be brought to the spot light. First, DZ-Cr-37 (Tsedeay) was previously found to be highly stable for grain yield in different environments from the present study (Truneh *et al.*, 1999). DZ-Cr-37 was released in 1984, and is currently the most widely grown tef variety in the relatively low altitude and moisture-stress prone areas. The other variety and which was found to be highly stable, DZ-Cr-255 (Ghibe), was released in 1993 on the grounds of specific adaptation to the south and southwest regions of Ethiopia (Hailu Tefera, personal communication). These results are testimonial to the effectiveness of selection in the national tef project in the development of varieties both for specific and wide adaptation. For unknown reason, DZ-Cr-255 is not as widely adopted by farmers as DZ-Cr-37. Tef breeders in the region therefore will have to consider popularization of DZ-Cr-255, and selecting higher yielding and more stable tef varieties than DZ-Cr-37 as the starting challenges.

Second, DZ-Cr-37 and DZ-Cr-255 are early maturing varieties (Hailu *et al*., 1995). The negative correlations between days-to-heading (r= -0.323***) and days-to-mature (r= -0.245**) with grain yield at these locations (Truneh, 1999) also corroborate the better adaptation of early maturing varieties than the late ones in SNNPR.

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Table 1. Combined and AMMI analyses of variance for grain yield (kg ha^{-1}) of 22 tef genotypes grown at four locations in SNNPR, 2002/03.

Source	df	Sum of square (SS)	Mean square	% SS
Locations (L)	3	3968.7	1322.9**	53
Genotypes (G)	21	1436.4	68.4**	20
G x E	63	1965.6	31.2**	27
IPCA1	23	349.6	15.2**	-
IPCA2	21	241.5	11.5ns	-
IPCA3	19	85.5	4.5ns	-
Residual	168	2822.4	16.8	(38)*
CV (%)	-		21.3	-

Note. The rest 62% of the total variance in the combined analysis is contributed by L, G, and G x L (remaining variance).

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Table 2. Mean grain yield (kg ha^{-1}) and scores of genotypes and environments to the first IPCA of 22 tef genotypes grown at four locations in SNNPR, 2002/03..

Genotypes	Location				Mean	IPCA 1 score
	Areka-**A***	Humbo-**B**	Hossana-**C**	Alaba-**D**		
DZ-01-1278-**a***	1859(12)	3136(1)	2444(11)	1610(4)	2262(3)	-2.3777
DZ-01-2053-**b**	1923(9)	1614(19)	2381(13)	1695(1)	1903(10)	0.6684
Tseday(DZ-Cr-37)-**c**	2799(1)	2481(2)	2918(2)	1473(10)	2418(1)	0.1695
Magna(DZ-01-196)-**d**	1862(11)	2212(5)	2167(20)	1281(16)	1881(12)	-0.8524
DZ-01-787-**e**	2273(3)	2071(6)	2682(5)	1378(14)	2101(5)	0.2881
Enatit(DZ-01-354)-**f**	1411(18)	1949(11)	2376(14)	1444(12)	1795(16)	-0.4976
Gibe(DZ-Cr-255)-**g**	2548(2)	2358(4)	2637(7)	1694(2)	2309(2)	-0.0281
Dukem(DZ-01-974)-**h**	2262(4)	1947(12)	2988(2)	1448(11)	2162(4)	0.8285
Ziquala(DZ-Cr-358)-**i**	1284(20)	2418(3)	2341(17)	1566(5)	1902(11)	-1.5542
DZ-Cr-82-**j**	2201(5)	1881(13)	2359(15)	1507(6)	1987(9)	0.3238
DZ-Cr-44-**k**	2145(6)	1955(10)	1845(22)	1246(17)	1798(14)	-0.4006
DZ-01-99-**l**	1166(21)	1831(15)	1940(21)	1060(22)	1499(22)	-0.9549
DZ-01-117-**m**	1728(15)	1972(9)	2298(19)	1189(18)	1797(15)	-0.3854
DZ-01-46-**n**	1594(17)	1540(20)	2434(12)	1333(15)	1725(19)	0.5119
DZ-01-1573B-**o**	1909(10)	2037(7)	2555(8)	1483(8)	1996(8)	-0.0625
DZ-01-1378B-**p**	1966(8)	1832(14)	2473(9)	1144(20)	1854(13)	0.2576
HO-Cr-136-**q**	1790(14)	1732(18)	3269(1)	1481(9)	2068(7)	1.1097
HO-Cr-198-**r**	2087(7)	2008(8)	2805(4)	1382(13)	2071(6)	0.3669
DZ-01-2470-**s**	922(22)	1772(16)	2776(5)	1501(7)	1743(18)	-0.2603
DZ-01-2457-**t**	1801(13)	1222(21)	2341(18)	1667(3)	1758(17)	1.3004
DZ-01-2462-**u**	1651(16)	956(22)	2358(16)	1134(21)	1525(21)	1.6205
DZ-01-2507-**v**	1403(19)	1742(17)	2456(10)	1150(19)	1688(20)	-0.0714
Mean	1845	1939	2492	1403	1920	
CV (%)	25.7	14.9	22.4	16.1	21.3	
LSD (5%)	783	475	920	373	661	
IPCA1 score	1.5491	-3.5285	1.6581	0.3213		

Note. Lower and upper case letters are designations for genotypes and sites, respectively.
a-l are released varieties and the rest advanced genotypes.

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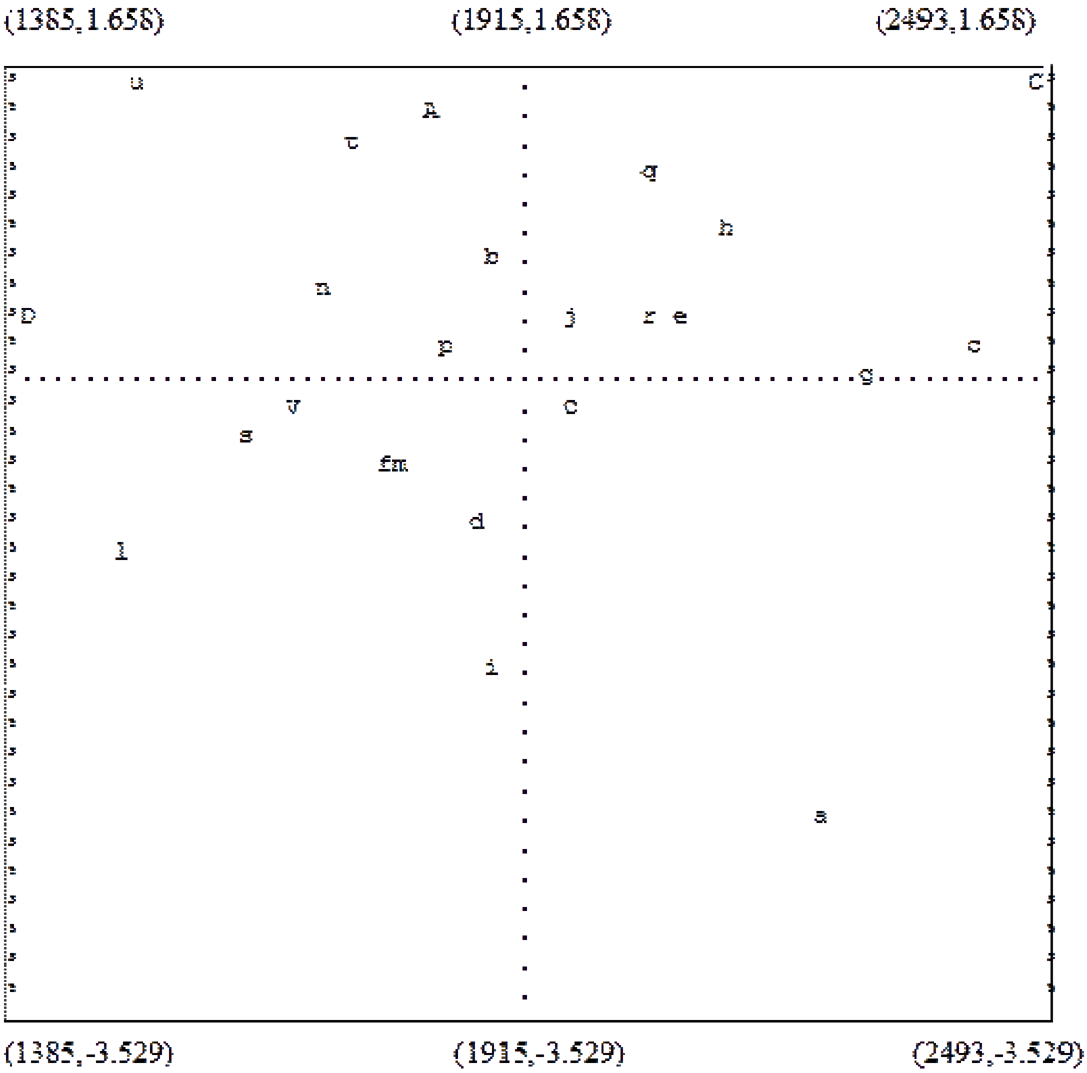

Figure 1. Biplot of genotypes (lower cases) and environments (upper cases) for grain yield using the first IPCA as ordinate and main effects as abscissa. *Note: Environments with similar means are not shown.*